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# PATENT ABSTRACTS OF JAPAN

(11)Publication number : 10-305353
(43)Date of publication of application : 17.11.1998

(51)Int.Cl. B22D 11/10
B22D 11/10

(21)Application number : 09-117981
(22)Date of filing : 08.05.1997

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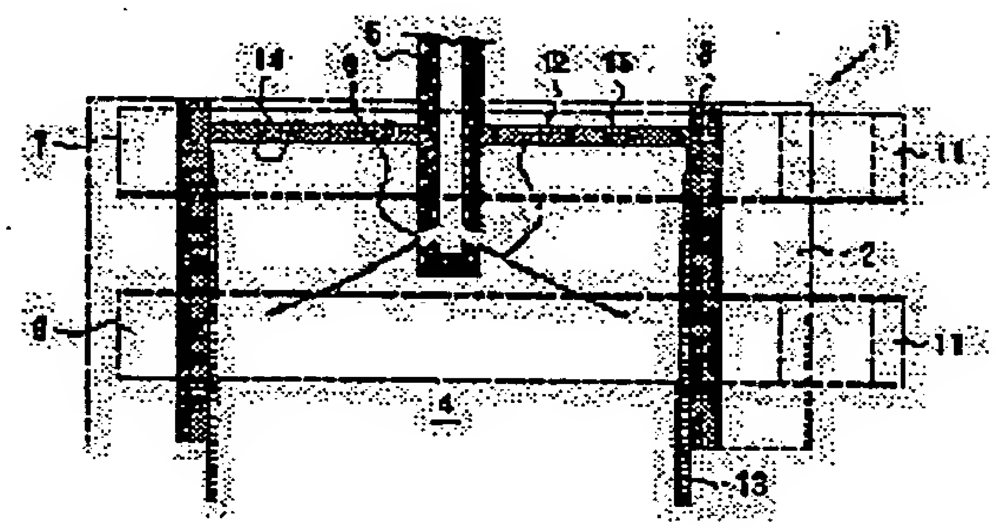
## (54) CONTINUOUS MOLDING OF STEEL

(57)Abstract:
PROBLEM TO BE SOLVED: To obtain a billet containing a less quantity of a non metallic enclosure in a face layer part and an inside layer part of the billet by controlling a flow of a molten steel in a mold, by utilizing a magnetic field.
SOLUTION: A process for continuous molding of steel comprising arranging magnetic poles 7, 8 standing against as upper and lower two stairs at the back face of a long side 2 of a mold to place the long side 2 of the mold between the upper and lower sides of a discharge hole 6 of a dipping nozzle 5 and controlling a flow of the molten steel 4 in the mold by charging magnetic fields, wherein the magnetic fields charged by the magnetic poles 7 and 8 are made so as to be (1) at least the magnetic field charged by the lower magnetic pole 8 is a magnetic field superimposed by a direct current static magnetic field (DC-StMF) and an alternating current shifting magnetic field (AC-ShMF) or (2) the magnetic fields charged by the upper magnetic pole 7 is a magnetic field superimposed by the DC-StMF and the DC-ShMF and the magnetic field charged by the lower magnetic pole 8 is the DC-StMF.



## LEGAL STATUS

[Date of request for examination] 22.04.2002
[Date of sending the examiner's decision of rejection]
[Kind of final disposal of application other than the examiner's decision of rejection or application converted registration]
[Date of final disposal for application]
[Patent number]
[Date of registration]
[Number of appeal against examiner's decision of rejection]
[Date of requesting appeal against examiner's decision of rejection]
[Date of extinction of right]

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(19)日本国特許庁（ＪＰ）　(12)公開特許公報（Ａ）　(11)特許出願公開番号

特開平10－305353

(43)公開日　平成10年(1998)11月17日

| (51)Int.Cl.⁶ | 識別記号 | 庁内整理番号 | F I | | | 技術表示箇所 |
|---|---|---|---|---|---|---|
| B22D 11/10 | | | B22D 11/10 | | L | |
| | 350 | | | 350 | Z | |
| | | | | 350 | B | |

審査請求　未請求　請求項の数３　ＯＬ　（全７頁）

(21)出願番号　特願平　9－117981

(22)出願日　平成９年　(1997)５月８日

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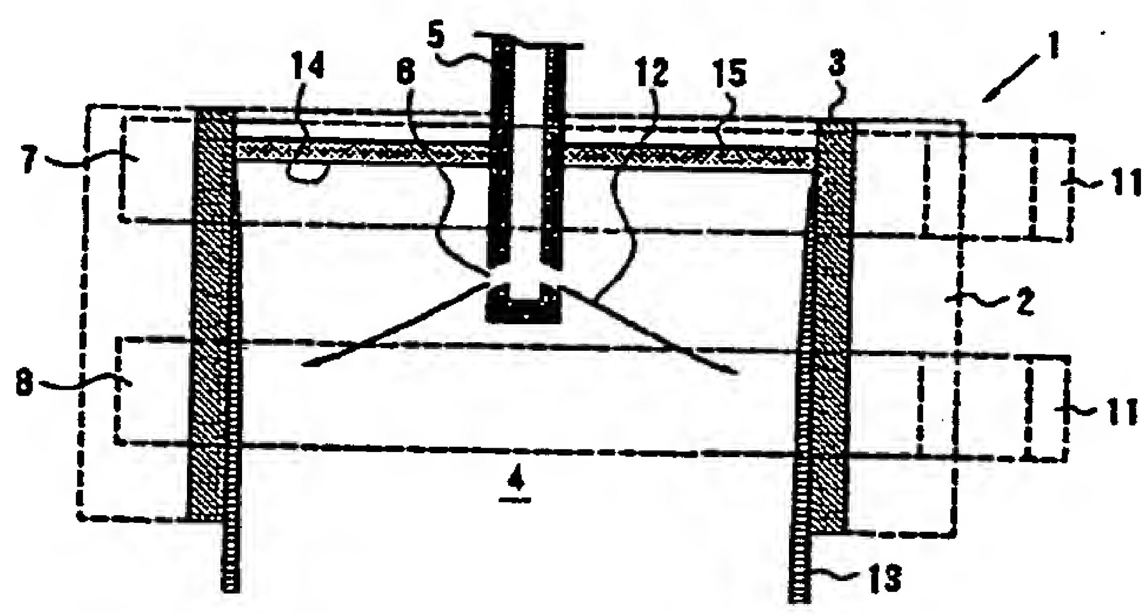
(54)【発明の名称】鋼の連続鋳造方法

(57)【要約】

【課題】　磁界を利用して鋳型内溶鋼の流動を制御し、鋳片の表層部及び内層部共に非金属介在物の少ない鋳片を得る。

【解決手段】　浸漬ノズル５の吐出孔６より上側と下側に鋳型長辺２を挟み対向する上下２段の磁極７、８を鋳型長辺背面に配置し、これら磁極にて磁界を印加して鋳型内溶鋼４の流動を制御する鋼の連続鋳造方法において、（１）少なくとも下側に配置した磁極８にて印加する磁界を直流静磁界と交流移動磁界とが重畳された磁界とするか、又は、（２）上側に配置した磁極７にて印加する磁界を直流静磁界と交流移動磁界とが重畳された磁界とし、且つ、下側に配置した磁極にて印加する磁界を直流静磁界とする。



【特許請求の範囲】

【請求項１】　浸漬ノズルの吐出孔より上側と下側に鋳型長辺を挟み対向する上下２段の磁極を鋳型長辺背面に配置し、これら磁極にて磁界を印加して鋳型内溶鋼の流動を制御する鋼の連続鋳造方法において、少なくとも下側に配置した磁極にて印加する磁界が直流静磁界と交流移動磁界とが重畳された磁界であることを特徴とする鋼の連続鋳造方法。

【請求項２】　浸漬ノズルの吐出孔より上側と下側に鋳型長辺を挟み対向する上下２段の磁極を鋳型長辺背面に配置し、これら磁極にて磁界を印加して鋳型内溶鋼の流動を制御する鋼の連続鋳造方法において、上側に配置した磁極にて印加する磁界が直流静磁界と交流移動磁界とが重畳された磁界であり、且つ、下側に配置した磁極にて印加する磁界が直流静磁界であることを特徴とする鋼の連続鋳造方法。

【請求項３】　磁極に直流用コイルと交流用コイルとを独立して配置し、それぞれのコイルに直流電流と交流電流とを独自に印加して、直流静磁界と交流移動磁界とが重畳された磁界を発生させることを特徴とする請求項１又は請求項２に記載の鋼の連続鋳造方法。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、鋳型内溶鋼に磁界を印加して磁界と溶鋼とによる電磁気力にて鋳型内溶鋼の流動を制御し、鋳片の表層部及び内層部共に非金属介在物の少ない鋳片を得ることができる鋼の連続鋳造方法に関するものである。

【０００２】

【従来の技術】鋼の連続鋳造においては、タンディッシュから浸漬ノズルを介し、鋳型短辺に向けて鋳型内に注入された溶鋼の吐出流は、鋳型短辺側の凝固シェルに衝突して下降流と上昇流とに分岐し、そして、下降流は鋳片の未凝固層深部に侵入し、又、上昇流は鋳型内溶鋼表面（以下、「メニスカス」と記す）で鋳型短辺から浸漬ノズルに向かう流れとなり、メニスカスに渦や盛り上がり等の流れの乱れを生成する。脱酸生成物であるアルミナを主体とする酸化物は、前記下降流により鋳片の未凝固層深くまで侵入して鋳片の内層部に捕捉され、又、メニスカス上に添加されたモールドパウダーは、前記上昇流によるメニスカスの渦や盛り上がりにより溶鋼中に巻き込まれ、鋳片の表層部に捕捉される。そして、これらに起因する非金属介在物が鋳片の品質欠陥の主要な原因であり、この現象は鋳片引抜き速度の増速に伴う吐出流速の高速度化に伴い顕著となっている。

【０００３】従って、連続鋳造に際しては、鋳片の内層部及び表層部に捕捉される非金属介在物をいかにして同時に低減するかが課題であり、この課題解決策として溶鋼に磁界を印加し、磁界による電磁気力を利用して鋳型内溶鋼の流動を制御しようとする試みが数多く提案されている。

【０００４】例えば、特開平３－１４２０４９号公報には、対向する鋳型長辺各背面の上下に設置した上下各一対の磁極の間で、鋳片の幅全体にわたり直流静磁界を印加する方法が開示されている。同号公報によれば、下部の直流静磁界で前記下降流を減速し、又、上部の直流静磁界で前記上昇流を減速することができるので、脱酸生成物もモールドパウダーも捕捉されない清浄な鋳片を製造できるとしている。しかしこの方法では、下降流及び上昇流が共に減速されるので、鋳型内の溶鋼流動が全体に緩慢となり、鋳片表層部に相当する位置の凝固シェル界面において、溶鋼流動による非金属介在物を洗浄する効果が減少し、鋳片表層部に脱酸生成物やガス気泡が捕捉される。

【０００５】特開平１－１５０４５０号公報には、メニスカスの下約１．５ｍから４．０ｍの範囲に、鋳片を挟んで対向して配置した磁極の間で、直流又は永久磁石による静磁界もしくは低周波交流磁界を印加し、磁界を通過する溶鋼流即ち前記下降流を減速・分散させ、鋳片内層部の非金属介在物を低減する技術が開示されている。しかしこの方法では、磁界設置位置が鋳型下方であるために前記上昇流の制御は不可能で、鋳片表層部のモールドパウダーの巻き込みは防止できない。

【０００６】特開昭６４－２７７１号公報には、鋳型長辺背面に低周波交流電源による交流移動磁界発生装置を複数対、鋳型を挟んで対向して配置し、溶鋼を磁界の移動方向に移動させて、吐出流を減速又は加速して鋳型内溶鋼の流動を制御する装置が開示されている。しかしこの装置では、磁界の移動方向にしか制動力が作用しないため、流動制御手段としては不十分である。更に、磁界が強過ぎるときには溶鋼流の回り込みが発生したり、又、移動磁界による溶鋼の付随流れが発生するため、吐出流速と磁界強度とのバランスがくずれた場合には、メニスカスに渦や盛り上がりを発生させて、モールドパウダーの巻き込みを助長することがある。

【０００７】又、特開平６－２２６４０９号公報には、鋳型長辺背面の浸漬ノズル吐出孔位置より上に交流移動磁界発生装置を配置し、水平方向に回転する磁界を印加してメニスカスの溶鋼を回転撹拌させ、この溶鋼流により、凝固シェル界面の非金属介在物を洗浄する効果を高めることで鋳片表層部の非金属介在物を低減すると共に、鋳型長辺背面の浸漬ノズル吐出孔位置より下に静磁界を印加して、前記下降流を減速して鋳片内層部の非金属介在物を低減する方法が開示されている。しかしこの方法では、メニスカスの溶鋼流速は必ずしも最適には制御されず、逆に、移動磁界による回転流でメニスカスの溶鋼流速が加速され、モールドパウダーの巻き込みを助長することもあり、鋳片品質の安定性に欠ける。 NSC ?

【０００８】

【発明が解決しようとする課題】このように従来の磁界

を利用した鋳型内溶鋼の流動制御の方法に関して、いずれの方法も、非金属介在物の低減にその効果を十分に発揮しているとは言い難く、改善の余地が大きいのが現状である。

【０００９】本発明は、上記事情に鑑みなされたもので、その目的とするところは交流移動磁界と静磁界とを同一磁極から重畳して印加し、鋳型内溶鋼の流動を最適に制御して鋳片の表層部及び内層部共に非金属介在物の少ない鋳片を得ることができる鋼の連続鋳造方法を提供することである。

【００１０】

【課題を解決するための手段】第１の発明による鋼の連続鋳造方法は、浸漬ノズルの吐出孔より上側と下側に鋳型長辺を挟み対向する上下２段の磁極を鋳型長辺背面に配置し、これら磁極にて磁界を印加して鋳型内溶鋼の流動を制御する鋼の連続鋳造方法において、少なくとも下側に配置した磁極にて印加する磁界が直流静磁界と交流移動磁界とが重畳された磁界であることを特徴とするものである。

【００１１】直流静磁界中を溶鋼が移動すると溶鋼中に渦電流が発生し、この渦電流と直流静磁界とにより溶鋼の移動方向と逆方向に電磁気力が作用して溶鋼流が減速される。本発明においては浸漬ノズル吐出孔より下側に対向して配置した下部磁極から直流静磁界と交流移動磁界とが重畳された磁界が溶鋼に印加される。この重畳された磁界のうちの直流静磁界は対向する磁極間、即ち鋳型長辺を貫通して溶鋼に印加されるので、この直流静磁界中を移動する吐出流が制動され減速する。そのため吐出流から分岐する下降流は減速されて鋳片の未凝固層深くまで侵入することがなく、鋳片内層部には脱酸生成物であるアルミナを主体とする酸化物のない清浄な鋳片を得ることができる。又、吐出流から分岐する上昇流も減速されて、メニスカスにおける渦や盛り上がり等の流れの乱れが防止される。

【００１２】又、重畳された磁界のうちの交流移動磁界により、鋳型内の溶鋼は強制的に水平方向に回転撹拌される。そのため、鋳片表層部に相当する位置の溶鋼が回転移動し、この溶鋼の移動により凝固シェル界面における非金属介在物の洗浄効果が確保され、鋳片表層部へのアルミナ等脱酸生成物及びガス気泡の捕捉が防止でき、鋳片表層部の清浄性が向上する。

【００１３】尚、浸漬ノズル吐出孔より上側に対向して配置した上部磁極から印加する磁界は、直流静磁界、交流移動磁界、又は、直流静磁界と交流移動磁界とが重畳された磁界の１つを選択すればよい。直流静磁界を用いた場合には、メニスカスにおける溶鋼流を直接減速することができるので、メニスカスでの溶鋼流が安定して渦や盛り上がり等の溶鋼流れの乱れが防止され、モールドパウダーの鋳片への巻き込みが防止される。交流移動磁界を用いた場合には、メニスカスの溶鋼を水平方向に回転撹拌させ、溶鋼流による凝固シェル界面の非金属介在物の洗浄効果を高めることで鋳片表層部の非金属介在物を低減することができる。その際、下部磁極でも同一方向に回転撹拌させるので、上部磁極の撹拌力を減じることができ、そのため、メニスカスの溶鋼流は過度に増速しないので、モールドパウダーの巻き込みが防止できる。又、直流静磁界と交流移動磁界とが重畳された磁界を用いた場合には、直流静磁界と交流移動磁界の両方の効果が期待できる。



【００１４】このように重畳して磁界を印加することで、２種類の異なる効果を発揮する磁界を狭い鋳型内に複数段配置することができる。

【００１５】第２の発明による鋼の連続鋳造方法は、浸漬ノズルの吐出孔より上側と下側に鋳型長辺を挟み対向する上下２段の磁極を鋳型長辺背面に配置し、これら磁極にて磁界を印加して鋳型内溶鋼の流動を制御する鋼の連続鋳造方法において、上側に配置した磁極にて印加する磁界が直流静磁界と交流移動磁界とが重畳された磁界であり、且つ、下側に配置した磁極にて印加する磁界が直流静磁界であることを特徴とするものである。

【００１６】本発明においては浸漬ノズル吐出孔より下側に対向して配置した下部磁極から直流静磁界が印加される。そのため上述したように、下降流は鋳片の未凝固層深くまで侵入することがなく、鋳片内層部は脱酸生成物であるアルミナを主体とする酸化物のない清浄な鋳片を得ることができる。

【００１７】又、浸漬ノズル吐出孔より上側に対向して配置した上部磁極から直流静磁界と交流移動磁界とが重畳された磁界を印加する。重畳された磁界のうちの交流移動磁界により鋳型内の溶鋼を強制的に水平方向に回転撹拌させ、又、重畳された磁界のうちの直流静磁界によりメニスカスの溶鋼流を減速する。こうして、上述したように介在物の洗浄効果を確保すると共に、モールドパウダーの巻き込みが防止され、鋳片表層部の清浄性が向上する。

【００１８】第３の発明による鋼の連続鋳造方法は、第１の発明又は第２の発明による鋼の連続鋳造方法において、磁極に直流用コイルと交流用コイルとを独立して配置し、それぞれのコイルに直流電流と交流電流とを独自に印加して、直流静磁界と交流移動磁界とが重畳された磁界を発生させることを特徴とするものである。

【００１９】直流電流と交流電流とを独自に印加するので、重畳された直流静磁界の磁束密度と交流移動磁界の磁束密度とを自由に決めることができる。そのため鋳型内溶鋼の流動制御が一層容易となり、清浄性の高い鋳片を製造することができる。

【００２０】

【発明の実施の形態】本発明を図面に基づき説明する。図１は、本発明を適用した鋳片断面が矩形型の連続鋳造機鋳型部の正面断面の概要図であり、図２は側面断面の

概要図、図３は図２のＸ－Ｘ面の部分断面の概要図である。

【００２１】図において、相対する鋳型長辺２と、鋳型長辺２内に内装された相対する鋳型短辺３とから鋳型１が構成されている。鋳型１の上方に、溶鋼４を収納した図示せぬタンディッシュが配置されており、タンディッシュ内の溶鋼４は、タンディッシュの底部に配置された浸漬ノズル５を介し、浸漬ノズル５の下部に設けられ、且つ鋳型１内の溶鋼４に浸漬した吐出孔６から、吐出流１２を鋳型短辺３に向けて鋳型１内に注入される。そして、溶鋼４は鋳型１内で冷却されて凝固シェル１３を形成し、鋳型１の下方に連続的に引き抜かれ鋳片となる。鋳型１内のメニスカス１４上には、溶鋼４の保温剤及び凝固シェル１３と鋳型１との潤滑剤として、モールドパウダー１５が添加されている。

【００２２】鋳型長辺２の背面上部には、吐出孔６より上側に鋳造方向の中心を位置させて、上部磁極７、７が、鋳型長辺２を挟みメニスカス１４を含む位置に、対向して配置されており、上部磁極７、７はリターンヨーク１１にて鋳型短辺３の背面で連結されている。又、鋳型長辺２の背面下部には、吐出孔６より下側に鋳造方向の中心を位置させて、下部磁極８、８が、鋳型長辺２を挟んで対向して配置されており、下部磁極８、８は鋳型短辺３の背面でリターンヨーク１１にて連結されている。これら上部磁極７及び下部磁極８の鋳型長辺２側には、鋳型１の幅方向で櫛の歯型状に複数の凸部１６が設けられており、この凸部１６の全てに直流交流兼用コイル９が巻かれている。又、上部磁極７及び下部磁極８の櫛型の基部に相当する位置には直流用コイル１０が巻かれている。

【００２３】この直流交流兼用コイル９に直流電流と交流電流とを重畳して印加すれば、直流静磁界と交流移動磁界とが重畳した磁界が鋳型１内に発生する。尚、直流交流兼用コイル９と交流電源とは、溶鋼４が水平方向に一方向回転するような移動磁界を形成するように結線する。印加する交流電流は、周波数が０．１Ｈｚ～１００Ｈｚの３相交流、又は位相を９０度とした２相交流を用いることが好ましい。周波数が０．１Ｈｚ以下では撹拌力が弱く、又、１００Ｈｚを超えると銅製の鋳型１での磁束の減衰が大きくなって鋳型１内の磁束密度を確保しにくくなるためであり、又、溶鋼を水平回転撹拌する容易さから、位相を９０度とした２相交流が好ましい。

【００２４】又、直流交流兼用コイル９には交流電流のみ印加し、直流電流は直流用コイル１０に独自に印加すれば、重畳された直流静磁界の磁束密度と交流移動磁界の磁束密度とを自由に決めることができるので好ましい。尚、直流交流兼用コイル９又は直流用コイル１０に直流電流のみ印加すれば鋳型１を挟み対向する磁極間で直流静磁界のみが得られ、直流交流兼用コイル９に交流電流のみ印加すれば交流移動磁界のみが得られる。

【００２５】本発明では、少なくとも下部磁極８に直流電流と交流電流とを重畳させて印加する場合（ケース１）と、上部磁極７に直流電流と交流電流とを重畳させて印加すると共に、下部磁極８に直流電流のみを印加する場合（ケース２）とがある。ケース１の場合に上部電極７に印加する電流は、直流電流、交流電流、又は、直流電流と交流電流との重畳のうちの１つを適宜選択して印加すればよい。各々の電流により前述した効果が期待できる。

【００２６】そして鋳造に当たり、直流静磁界の鋳型１厚みの中心における磁束密度を０．１テスラ以上、交流移動磁界の鋳型１内壁近傍の磁束密度を０．００５テスラ～０．２テスラとなるように電流又は電圧を調整する。直流静磁界の磁束密度が０．１テスラ未満、及び交流移動磁界の磁束密度が０．００５テスラ未満では、共に溶鋼４に作用する電磁気力が弱く、溶鋼流動の制御が不可能となるためであり、又、交流移動磁界の磁束密度が０．２テスラを超えると、撹拌力が強過ぎてメニスカス１４の溶鋼流が速くなり、モールドパウダー１５の巻き込みの虞があるためである。尚、交流移動磁界による溶鋼に作用する電磁気力は周波数と磁束密度の二乗との積に比例する。鋳造に当たり、交流移動磁界に印加する周波数と交流移動磁界の磁束密度の二乗との積が、２．$5\times10^{-3}$～１．$5\times10^{-1}$（Ｈｚ・テスラ$^2$）の範囲を目標とすれば、交流移動磁界により溶鋼は十分に撹拌される。

【００２７】又、図４は本発明の別の実施の形態を示した連続鋳造機の側面断面の概要図であり、上部磁極７と下部磁極８とがリターンヨーク１１にて鋳型長辺２の背面で連結されている。この場合には上下磁極７、８の片方でのみ直流静磁界を印加することができないが、設備を小型化できるので、設備費用的には有利である。

【００２８】

【実施例】

〔実施例１〕図１に示す構成の連続鋳造機を用いた本発明の実施例を以下に説明する。

【００２９】鋳片断面寸法が、厚み２２０ｍｍ、幅１２００ｍｍであるスラブ連続鋳造機にて、炭素濃度が０．００５ｗｔ％の極低炭素Ａｌキルド鋼を鋳片引抜き速度２．５ｍ／ｍｉｎで鋳造した。使用した浸漬ノズルは、吐出孔径が８５ｍｍ、吐出孔角度が下向き２５度で、浸漬ノズルの浸漬深さ（メニスカスから吐出孔上端までの距離）は２３０ｍｍである。又、メニスカス位置は鋳型上端から１２０ｍｍの位置で、鋳型長さは９５０ｍｍである。

【００３０】上部磁極は、鋳造方向の長さが２４０ｍｍ、鋳型幅方向の長さが１９５０ｍｍであり、メニスカス位置が上部磁極の鋳造方向の上端から１００ｍｍの位置となるように配置した。又、下部磁極は、鋳造方向の長さが２４０ｍｍ、鋳型幅方向の長さが１９５０ｍｍで

あり、鋳造方向の中心位置を吐出孔下端から250mmの位置として配置した。この位置は吐出流が鋳型短辺側の凝固シェルに衝突する点より鋳造方向の上側である。そして、上部磁極及び下部磁極とも直流交流兼用コイルを巻く凸部の幅を225mmとし、凸部を各磁極に6つずつ配置した。

【0031】交流電流は、周波数が60Hzの3相交流電源を用い、本実施例では直流静磁界と交流移動磁界とが重畳された磁界を形成する方法として、直流交流兼用コイルに直流電流と交流電流とを重畳して印加する方法を用いた。



【0032】直流静磁界の磁束密度の目標を鋳型厚み中心で0.25テスラとしたが、直流電流と交流電流とを重畳して印加した場合には、直流静磁界は交流移動磁界の影響を受け、0.20テスラ程度まで低下することがあった。又、交流移動磁界の磁束密度を鋳型内壁で0.12テスラ〜0.45テスラの範囲で変化させ、直流静磁界との整合がとれる条件下でメニスカスの溶鋼流が乱れない範囲で最大値となるように調整した。そして上部磁極と下部磁極の磁界を表1に示す組合せで印加した。

【0033】

【表1】

磁界印加条件と鋳片清浄性（同一コイルに重畳して印加）

| | 磁界印加条件 | | 鋳片清浄性評価 |
|---|---|---|---|
| | 上部磁極 | 下部磁極 | |
| 本発明の実施例 | 直流 | 直流＋交流 | ＋＋ |
| | 交流 | 直流＋交流 | ＋＋ |
| | 直流＋交流 | 直流＋交流 | ＋＋＋ |
| | 直流＋交流 | 直流 | ＋＋ |
| 比較例 | 直流 | 直流 | ＋ |
| | 交流 | 直流 | ＋ |
| | 直流 | 交流 | ＋ |
| | 交流 | 交流 | ＋ |
| | 直流＋交流 | 交流 | ＋ |

＋＋＋；効果あり
＋＋　；比較的効果あり
＋　　；あまり効果が認められない

【0034】又、比較のために、上部磁極及び下部磁極に直流電流又は交流電流のみ印加した場合や、上部磁極に直流電流と交流電流とを重畳して印加し、且つ下部磁極に交流電流のみ印加した場合も実施した。比較例の磁界印加条件も表1に合わせて示す。

【0035】そして、得られた鋳片を薄鋼板に圧延して、薄鋼板を超音波探傷試験して非金属介在物による欠陥発生率を調査し、欠陥発生率が低いものは清浄性が高いとして評価した。調査結果を表1に示す。表1に示すように、本発明の実施例では、鋳片の清浄性が向上した。

【0036】〔実施例2〕本実施例では直流静磁界と交流移動磁界とが重畳された磁界を形成する方法として、交流電流を直流交流兼用コイルに印加し、直流電流を直流用コイルに印加する方法を用いた。その他の条件は実施例1と全く同じ条件である。

【0037】直流静磁界と交流移動磁界とが重畳された磁界を形成する場合でも、交流電流と直流電流とを独自に印加した本実施例では、直流静磁界と交流移動磁界との整合性の問題は緩和され、比較的自由に磁束密度を決定することができ、直流静磁界の鋳型厚み中心での磁束密度を常に0.25テスラ以上確保することができた。そして上部磁極と下部磁極の磁界を表2に示す組合せで印加した。

【0038】

【表2】

磁界印加条件と鋳片清浄性（別々のコイルに印加）

| | 磁界印加条件 | | 鋳片清浄性評価 |
|---|---|---|---|
| | 上部磁極 | 下部磁極 | |
| 本発明の実施例 | 直流 | 直流＋交流 | ＋＋＋ |
| | 交流 | 直流＋交流 | ＋＋＋ |
| | 直流＋交流 | 直流＋交流 | ＋＋＋＋ |
| | 直流＋交流 | 直流 | ＋＋＋ |
| 比較例 | 直流＋交流 | 交流 | ＋ |

＋＋＋＋：顕著な効果あり
＋＋＋　：効果あり
＋＋　　：比較的効果あり
＋　　　：あまり効果が認められない

【0039】又、比較例として上部磁極に直流電流と交流電流とを重畳して印加し、且つ下部磁極に交流電流のみ印加した場合も実施した。

【0040】そして、得られた鋳片を薄鋼板に圧延して、薄鋼板を超音波探傷試験して非金属介在物による欠陥発生率を調査し、欠陥発生率が低いものは清浄性が高いとして評価した。調査結果を表2に示す。表2に示すように、直流電流と交流電流とを独自に印加した本実施例では、より一層鋳片の清浄性が向上した。そして特に、上部磁極及び下部磁極とも直流電流と交流電流とを印加した条件で最高の清浄性が確保できた。

【0041】

【発明の効果】本発明では、吐出孔より下方に設けた直流静磁界により下降流の鋳片未凝固層への侵入が防止されて鋳片内層部の清浄性が向上すると共に、上昇流によるメニスカス近傍における流動が抑制されてモールドパウダーの巻き込みが大幅に低減し、更に、交流移動磁界にて溶鋼を水平方向に回転撹拌するため、凝固シェル界面における非金属介在物の洗浄効果が確保され、鋳片表層部の清浄性が向上する。その結果、内層部及び表層部が共に清浄な鋳片を安定して製造することが可能となった。

【図面の簡単な説明】

【図1】本発明を適用した鋳片断面が矩形型の連続鋳造機の鋳型部の正面断面の概要図である。

【図2】本発明を適用した鋳片断面が矩形型の連続鋳造機の鋳型部の側面断面の概要図である。

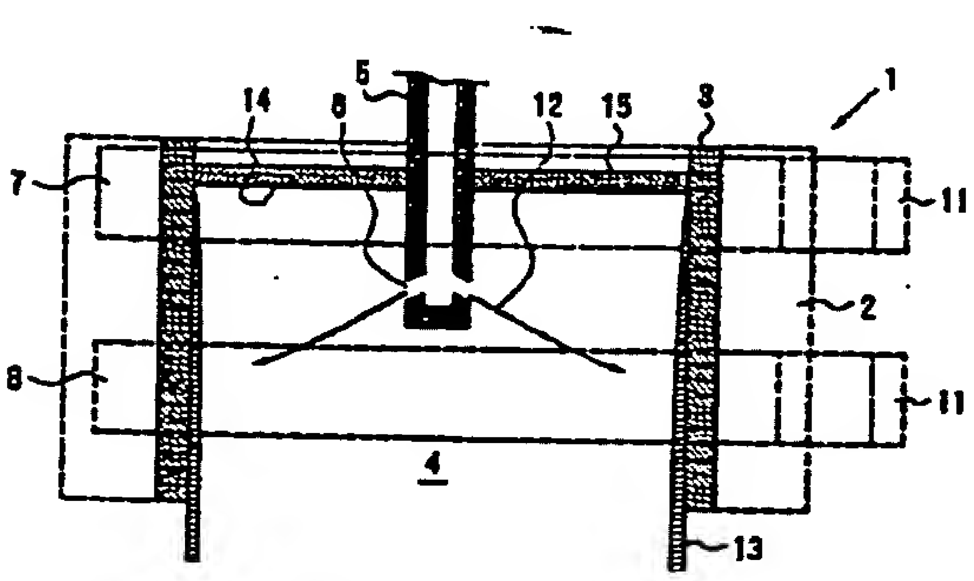
【図3】図2のX－X断面の概要図である。

【図4】本発明の別の実施の形態を示した連続鋳造機の側面断面の概要図である。

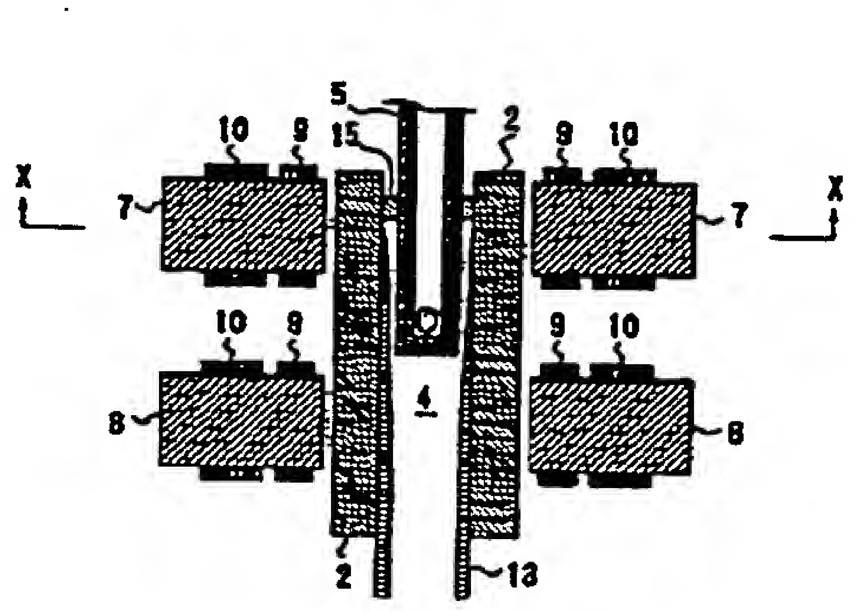
【符号の説明】

1　鋳型
2　鋳型長辺
3　鋳型短辺
4　溶鋼
5　浸漬ノズル
6　吐出孔
7　上部磁極
8　下部磁極
9　直流交流兼用コイル
10　直流用コイル
11　リターンヨーク
12　吐出流
13　凝固シェル
14　メニスカス
15　モールドパウダー

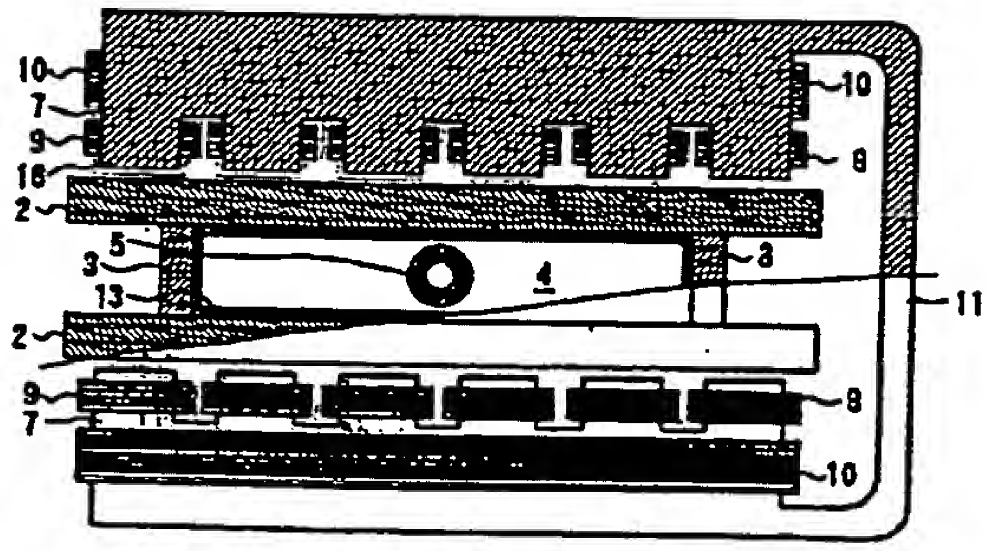
【図1】



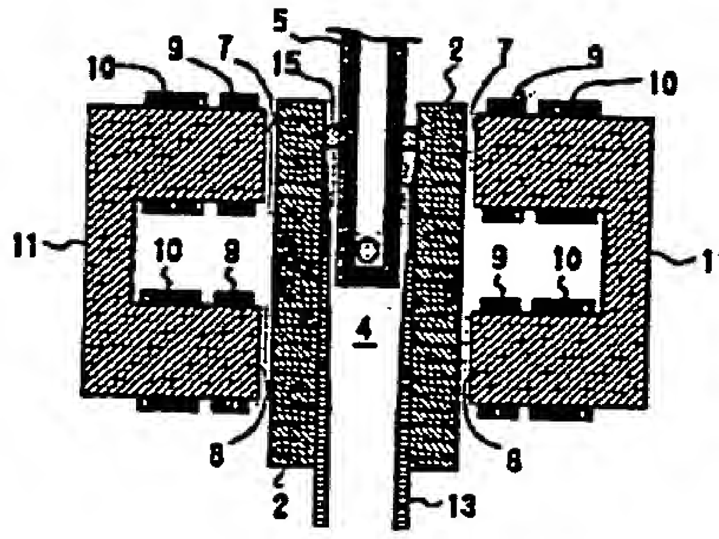

【図2】



【図3】


10
7
9
16
2
5
3
13
2
9
7
10
8
3
4
11
8
10

【図4】


5
10
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7
15
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9
10
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4
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2
13
8

PATENT PUBLICATION OF JAPAN

(11) Publication number: 10-305353

(43) Date of publication of application: 11. 17. 1998

(51) Int.Cl. B22D 11/10

(21) Application number: 9-117981

(22) Date of filing: 05. 08. 1997

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(54) [Title of the Invention] METHOD OF CONTINUOUS CASTING OF STEEL

(57) [Abstract]

[Problem] To obtain a slab both of whose surface and internal portions less contain non-metallic inclusions by making use of a magnetic field to control a flow of molten steel in a mold.

[Means for Solution] A method of continuous casting of steel in which above and below a discharge opening 6 of a submerged nozzle 5, upper side magnetic poles 7 that face each other with long side walls of the mold interposed therebetween and lower side magnetic poles that face each other with long side wall of the mold interposed therebetween are disposed on rear surfaces of the long side walls of the mold, a magnetic field is applied with the magnetic poles, and thereby a flow of the molten steel 4 in the mold is controlled. In the above, (1)

at least magnetic poles 8 located at the lower side applies a magnetic field in which a static magnetic field and an alternating shifting magnetic field are superposed, or (2) the magnetic poles 7 located at the upper side applies a magnetic field in which a static magnetic field and an alternating shifting magnetic field are superposed and the magnetic poles located at the lower side applies a static magnetic field.

[Claims]

1. A method of continuous casting of steel in which above and below a discharge opening of a submerged nozzle, upper side magnetic poles that face each other with long side walls of a mold interposed therebetween and lower side magnetic poles that face each other with long side walls of the mold interposed therebetween are disposed on rear surfaces of the long side walls of the mold, a magnetic field is applied with the magnetic poles, and thereby a flow of the molten steel in the mold is controlled, wherein at least the magnetic poles located on the lower side apply a magnetic field in which a static magnetic field and an alternating shifting magnetic field are superposed.

2. A method of continuous casting of steel in which above and below a discharge opening of a submerged nozzle, upper side magnetic poles that face each other with long side walls of a mold interposed therebetween and lower side magnetic poles that face each other with long side walls of the mold interposed therebetween are disposed on rear surfaces of the long side walls of the mold, a magnetic field is applied with the magnetic poles, and thereby a flow of the molten steel in the mold is controlled, wherein the magnetic poles located on the upper side apply a magnetic field in which a static magnetic field and an alternating shifting magnetic field are superposed and the magnetic poles located on the lower side apply a static

magnetic field.

3. A method of continuous casting of steel as set forth in claim 1 or claim 2, wherein a direct current coil and an alternating current coil are independently disposed to the magnetic poles, a direct current and an alternating current are independently applied to corresponding coils, and thereby a magnetic field in which a static magnetic field and an alternating shifting magnetic field are superposed is obtained.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belongs] The present invention relates to a method of continuous casting of steel in which a magnetic field is applied to molten steel in a mold, by an electromagnetic force generated by the magnetic filed and the molten metal, a flow of the molten steel in the mold is controlled, and thereby a slab of steel both of which surface portion and internal portion less contain nonmetallic inclusions can be obtained.

[0002]

[Prior Art] In the continuous casting of steel, a discharge flow of molten steel that is discharged from a tundish through a submerged nozzle toward a short sidewall of a mold into the mold collides onto a solidified shell on a short sidewall of the mold, resulting in branching into a descending flow and

an ascending flow. The descending flow intrudes into an un-solidified depth of the slab, and the ascending flow becomes a flow directing from the short sidewall of the mold to the submerged nozzle in a molten steel surface (hereinafter referred to as "meniscus") in the mold, resulting in causing disturbance such as a drift and swelling at the meniscus. Oxides mainly consisting of alumina that is a product formed by deoxidization are brought riding on the descending flow to the un-solidified depth of the slab and captured inside of the slab, in addition, mold powder added onto the meniscus is included in the molten steel because of the drift and swelling of the meniscus due to the ascending flow and captured in the surface portion of the slab. The nonmetallic inclusions caused by these are main causes of quality defect of the slab. This phenomenon has been conspicuous as a discharge flow rate becomes higher accompanying an increase in an extruding speed of steel.

[0003] Accordingly, when the continuous casting is implemented, it is a concern how to simultaneously reduce the nonmetallic inclusions captured inside of the slab and in the surface portion thereof. As a countermeasure to overcome the concern, there have been proposed many approaches in which by applying a magnetic field to the molten steel and by making use of an electromagnetic force due to the magnetic field, a flow of the molten steel in the mold is controlled.

[0004] For instance, in Japanese Patent Laid-Open No. HEI 3-142049, a method is disclosed in which between each pair of an upper pair and a lower pair of magnetic poles that are disposed, respectively, at upper and lower portions of rear surfaces of long sidewalls of the mold that face each other, over an entire width of the slab, a static magnetic filed is applied. According to the same publication, the descending flow is retarded by the static magnetic field applied at the lower portion, in addition, the ascending flow can be retarded by the static magnetic field applied at the upper portion. Accordingly, according to the publication, a clean slab in which the product that is formed through deoxidizing reaction and mold powder are not captured can be produced. However, in this method, since both of the descending and ascending flows are retarded, the flow of the molten steel in the mold is slowed down as a whole, in the solidified shell interface at a position corresponding to the slab surface portion, an effect of cleaning the nonmetallic inclusions due to the flow of the molten steel is reduced, and the product of the deoxidizing reaction and gas bubbles are captured in the surface portion of the slab.

[0005] In Japanese Patent Laid-Open No. HEI 1-150450, a technology is disclosed in which in the range of from substantially 1.5 m to 4.0 m below the meniscus, between magnetic poles disposed facing to each other with the slab

interposed therebetween, a static magnetic field due to a direct current or a permanent magnet or a low frequency alternating magnetic field is applied, thereby the flow of molten steel that goes past the magnetic field, that is, the descending flow is retarded and dispersed, resulting in decrease in the nonmetallic inclusions in the internal portion of the molten steel. However, in this technique, since the magnetic field is applied at the lower portion of the mold, it is impossible to control the ascending flow, as a result, the inclusion of the mold powder in the surface portion of the slab cannot be hindered from occurring.

[0006] In Japanese Patent Laid-Open No. SHO 64-2771, apparatus is disclosed in which a plurality of pairs of alternating shifting magnetic field generators due to a low frequency alternating current is disposed at rear surfaces of long sidewalls of the mold with the mold interposed therebetween, the molten steel is moved in a direction in which the magnetic field moves, thereby discharge flow is decelerated or accelerated, resulting in controlling the flow of the molten steel in the mold. However, in this method, since the braking force works only in a direction in which the magnetic field shifts, this is insufficient as the braking means against the flow. Furthermore, when the magnetic field is too strong, the flow of the molten steel goes around, furthermore accompanying flow of the molten steel due to the shifting magnetic field

is caused. Accordingly, when the discharge flow rate and the intensity of the magnetic field are out of balance, the drift or the swelling is caused at the meniscus, resulting in promoting the inclusion of the mold powder.

[0007] Furthermore, in Japanese Patent Laid-Open No. HEI 6-226409, a method is disclosed in which an alternating shifting magnetic field generator is disposed above a position of a discharge opening of a submerged nozzle on a rear surface of a long sidewall of the mold, therewith a magnetic field rotating in a horizontal direction is applied to rotate and agitate the molten steel at the meniscus, and by this flow of the molten steel, an effect of cleaning the nonmetallic inclusions at the interface of the solidified shell is improved, resulting in reducing the nonmetallic inclusions in the surface portion of the slab. In addition to the above, a static magnetic field is applied to a position below the discharge opening of the submerged nozzle on the rear surface of the long sidewalls of the mold, thereby the descending flow is decelerated, resulting in a decrease in the nonmetallic inclusions in the internal portion of the molten steel. However, in this method, the flow rate of the molten steel at the meniscus is not necessarily controlled to the optimum value, on the contrary, because of the rotation flow due to the shifting magnetic field, the flow rate of the molten steel at the meniscus is accelerated, the inclusion of the mold powder

is promoted, resulting in lacking stability of slab quality.

[0008]

[Problems that the Invention is to Solve]

Thus, all of existing methods that make use of the magnetic field for controlling the flow of the molten steel in the mold are not sufficiently exhibiting the effect in reducing the nonmetallic inclusions, that is, there is room for improvement.

[0009] The present invention is carried out in view of the above situations and intends to provide a method for continuous casting of steel in which an alternating shifting magnetic field and a static magnetic field are applied superposed from the same magnetic poles and the flow of the molten steel in the mold is controlled to be the optimum, thereby enabling to obtain a slab both surface portion and internal portion of which contain less nonmetallic inclusions.

[0010]

[Means for Solving the Problems] A method for continuous casting of steel according to a first invention is one in which above and below a discharge opening of a submerged nozzle, upper side magnetic poles and lower side magnetic poles that face each other with the long sidewalls of the mold interposed therebetween are disposed on rear surfaces of the long sidewalls of the mold, and with these magnetic poles a magnetic field is applied to control the flow of the molten steel in

the mold. In the above method, at least a magnetic field applied by the magnetic poles located at the lower side is one in which a static magnetic field and an alternating shifting magnetic filed are superposed.

[0011] When the molten steel moves in the static magnetic field, an eddy current is caused in the molten steel. Because of the eddy current and the static magnetic field, in an opposite direction to that of movement of the molten steel, an electromagnetic force works and the flow of the molten steel is retarded. In the present invention, from the lower side magnetic poles disposed opposed at lower side than the discharge opening of the submerged nozzle, a magnetic field in which the static magnetic field and the alternating shifting magnetic field are superposed is applied to the molten steel. The static magnetic field of the superposed magnetic field is applied between the magnetic poles that face each other, that is, applied penetratingly through the long sidewalls of the mold to the molten steel. Accordingly, the discharge flow that moves in the static magnetic field is braked and retarded. As a result, the descending flow that branches from the discharge flow is decelerated and does not intrude into the depth of the un-solidified layer of the slab. Thereby, a clean slab whose internal portion is free from oxides mainly consisting of alumina that is a product of the deoxidizing reaction can be obtained. Furthermore, the ascending flow that branches from

the discharge flow is also decelerated, thereby turbulence of the flow such as drift and swelling at the meniscus can be hindered from occurring.

[0012] Furthermore, owing to the alternating shifting magnetic field of the superposed magnetic field, the molten steel in the mold is forcibly rotated and agitated in a horizontal direction. Accordingly, the molten steel at a position corresponding to the surface of the slab is rotated and moved, and as a result of the movement of the molten steel, an effect of cleaning the nonmetallic inclusions at the solidified shell interface can be secured, thereby the capture of the products due to the deoxidizing reaction such as alumina and gas bubbles in the surface of the slab can be hindered from occurring, resulting in an improvement in cleanliness of the surface of the slab.

[0013] A magnetic field applied from the upper side magnetic poles disposed opposed at the upper side than the discharge opening of the submerged nozzle can be selected from any one of the static magnetic field, alternating shifting magnetic field, or a superposed magnetic field of the static magnetic field and the alternating shifting magnetic field. When the static magnetic field is used, since the flow of the molten steel at the meniscus can be directly decelerated, the flow of the molten steel at the meniscus can be stabilized, thereby turbulence of the flow of the molten steel such as drift or

the swelling can be hindered from occurring, resulting in hindering the inclusion of powder into the slab from occurring. When the alternating shifting magnetic field is used, the molten steel at the meniscus can be rotated and agitated in a horizontal direction, thereby an effect of cleaning the nonmetallic inclusions at the solidified shell interface due to the flow of the molten steel can be improved, resulting in a decrease in the nonmetallic inclusions at the surface of the slab. At that time, since even the lower magnetic poles facilitate rotating and agitating in the same direction, an agitating force of the upper magnetic poles can be reduced. Accordingly, since the flow of the molten steel at the meniscus is not excessively accelerated, the mold powder can be hindered from including. Still furthermore, when the superposed magnetic field of the static magnetic field and the alternating shifting magnetic field is used, the effects from both of the static magnetic field and the alternating shifting magnetic field can be expected.

[0014] When the magnetic fields are applied thus superposed, the magnetic field that can exhibit two kinds of different effects can be disposed in a plurality of stages in a narrow mold.

[0015] A method for continuous casting of steel according to a second invention is one in which above and below a discharge opening of a submerged nozzle, upper side magnetic poles and

lower side magnetic poles that face each other with the long sidewalls of the mold interposed therebetween are disposed on rear surfaces of the long sidewalls of the mold, and with these magnetic poles a magnetic field is applied to control the flow of the molten steel in the mold. In the above method, a magnetic field applied by the magnetic poles located at the upper side is one in which a static magnetic field and an alternating shifting magnetic filed are superposed, and a magnetic field applied by the magnetic poles located at the lower side is a static magnetic field.

[0016] In the present invention, the static magnetic field is applied from the lower side magnetic poles disposed opposed at the lower side than the discharge opening of the submerged nozzle. Accordingly, as mentioned above, since the descending flow does not intrude into the depth of the un-solidified layer of the slab, a clean slab whose internal layer portion is free from the oxides mainly consisting of alumina that is the product of deoxidizing reaction.

[0017] Furthermore, the magnetic field obtained by superposing the static magnetic field and the alternating shifting magnetic field is applied from the upper side magnetic poles disposed opposed at the upper side than the discharge opening of the submerged nozzle. Owing to the alternating shifting magnetic field of the superposed magnetic fields, the molten steel in the mold is forcibly rotated and agitated in

a horizontal direction, in addition, owing to the static magnetic field of the superposed magnetic fields, the flow of the molten steel at the meniscus is decelerated. Thus, as mentioned above, an effect of cleaning the inclusions is secured and the mold powder is inhibited from including, resulting in an improvement in cleanliness of the surface portion of the slab.

[0018] A method of continuous casting of steel according to a third invention, in the methods of continuous casting of steel according to the first or second invention, includes independently disposing a static coil and an alternating coil for the magnetic poles, independently applying a direct current and an alternating current to the corresponding coils, and generating a magnetic field in which the static magnetic field and the alternating shifting magnetic field are superposed.

[0019] Since the direct current and the alternating current are independently applied, the magnetic flux density of the static magnetic field and that of the alternating shifting magnetic field that are superposed on the former can be separately decided. Accordingly, the flow control of the molten steel in the mold can be made furthermore easily, resulting in producing the slab high in the cleanliness.

[0020]

[Embodiments] The present invention will be explained with reference to the drawings. Fig. 1 is schematic sectional front

view of a casting portion of a continuous casting system to which the present invention is applied and in which a section of a slab is rectangular, Fig. 2 is a schematic diagram showing a sectional side view, and Fig. 3 is a schematic diagram showing a partial section along an X-X surface of Fig. 2.

[0021] In the figures, a mold 1 is made of opposite long sidewalls 2 of the mold and opposite short sidewalls 3 of the mold, the short sidewalls 3 being installed inside of the opposite long sidewalls 2. Above the mold 1, a not shown tundish that accommodates molten steel 4 is disposed, and the molten steel 4 in the tundish is allowed discharging a discharge flow 12, through a submerged nozzle 5 disposed at a bottom portion of the tundish, from a discharge opening 6 that is disposed at a bottom of the submerged nozzle 5 and submerged in the molten steel 4 in the mold 1 toward the short sidewalls 3 of the mold into the mold 1. Then, the molten steel 4 is cooled in the mold 1 and forms a solidified shell 13, and the solidified shell is continuously extruded from the mold 1 downward and forms a slab. On a meniscus 14 in the mold 1, as a heat insulating agent of the molten steel 4 and a lubricant between the solidified shell 13 and the mold 1, mold powder 15 is added.

[0022] At upper portions of rear surfaces of the long sidewalls 2 of the mold, with a center in a casting direction disposed above the discharge opening 6, upper magnetic poles 7, 7 are

oppositely disposed at positions that sandwich the long sidewalls 2 of the mold and contain the meniscus 14, and the upper magnetic poles 7, 7 are joined together with a return yoke 11 behind the short sidewalls 3 of the mold. Furthermore, at lower portions of the rear surfaces of the long sidewalls 2 of the mold, with a center in a casting direction disposed below the discharge opening 6, lower magnetic poles 8, 8 are oppositely disposed with the long sidewalls 2 of the mold interposed therebetween, and the lower magnetic poles 8, 8 are joined together with a return yoke 11 behind the short sidewalls 3 of the mold. On a side of one long sidewall 2 of the mold of the upper magnetic pole 7 and the lower magnetic pole 8, in a width direction of the mold 1, a plurality of convexities 16 is disposed with a comb-tooth shape, and each of the convexities 16 is wound with a coil 9 for use in both direct current and alternating current. In addition, at a position corresponding to a basis of comb shape of the upper magnetic pole 7 and the lower magnetic pole 8, a coil 10 for use in direct current is wound.

[0023] When a direct current and an alternating current are applied superposed to the coil 9 for use in direct current and alternating current, a magnetic field in which a static magnetic field and an alternating shifting magnetic field are superposed is generated in the mold 1. The coil 9 for use both in direct current and alternating current and an alternating

power source are connected so as to form a shifting magnetic field that allows the molten steel 4 to rotate in one direction in a horizontal direction. An applying alternating current is preferable to be a three-phase alternating current having a frequency in the range of 0.1 Hz to 100 Hz, or a two-phase alternating current of which phase is set at 90 degree. When the frequency is 0.1 Hz or less, the agitation is weak, and when the frequency exceeds 100 Hz, since the magnetic flux is largely attenuated by the copper mold 1, the magnetic flux density in the mold 1 can be maintained with difficulty. In addition, in view of easiness of rotating and agitating the molten steel in a horizontal plane, the two-phase alternating current whose phase is set at 90 degree is preferable.

[0024] Furthermore, when only the alternating current is applied to the coil 9 for use in both the direct current and alternating current and the direct current is independently applied to the direct current coil 10, the magnetic flux of the static magnetic field and that of the alternating shifting magnetic field that is superposed on the former can be preferably separately determined. Furthermore, when only the direct current is applied to the coil 9 for use in both the direct current and alternating current or to the direct current coil 10, only the static magnetic field can be obtained between the magnetic poles that face with the mold 1 interposed therebetween, and when only the alternating current is applied

to the coil 9 for use both in the direct current and alternating current, only the alternating shifting magnetic field can be obtained.

[0025] In the present invention, there are a case 1 where the direct current and the alternating current are applied superposed at least to the lower magnetic poles 8 and a case 2 where the direct current and the alternating current are applied superposed to the upper magnetic poles 7 and only the direct current is applied to the lower magnetic poles 8. In the case 1, an electric current applied to the upper magnetic poles 7 may be appropriately selected from a direct current, an alternating current or one obtained by superposing the direct current and the alternating current. From the respective electric currents, corresponding aforementioned effects can be expected.

[0026] At the casting, the electric currents or voltages are adjusted so that the magnetic flux density of the static magnetic field at a center of a thickness of the mold 1 may be 0.1 T or more, and the magnetic flux density of the alternating shifting magnetic field in the neighborhood of an inner wall of the mold 1 may be in the range of 0.005 T to 0.2 T. When the magnetic flux density of the static magnetic field is less than 0.1 T and the magnetic flux density of the alternating shifting magnetic field is less than 0.005 T, in both cases, since an electromagnetic force acting on the molten

steel 4 is weak, the flow of the molten steel cannot be controlled. In addition, when the magnetic flux density of the alternating shifting magnetic field exceeds 0.2 T, an agitating force becomes too strong, the flow of the molten steel at the meniscus 14 becomes fast, there is concern about the inclusion of the mold powder 15. The electromagnetic force acting on the molten steel caused by the alternating shifting magnetic field is in proportion to a product of a frequency and a square of the magnetic flux density. At the casting, when the product of the frequency applied to the alternating shifting magnetic field and a square of the magnetic flux density of the alternating shifting magnetic field is set in the range of $2.5 \times 10^{-3}$ to $1.5 \times 10^{-1}$ ($Hz \cdot T^2$), the molten steel can be sufficiently agitated owing to the alternating shifting magnetic field.

[0027] Still furthermore, Fig. 4 is a schematic sectional side view of a continuous casting system showing another embodiment of the present invention, the upper magnetic pole 7 and the lower magnetic pole 8 are connected with the return yoke 11 behind the long sidewall 2 of the mold. In this case, though the static magnetic field cannot be applied with only one of the upper and lower magnetic poles 7, 8, equipment can be formed smaller in size, that is, it is advantageous from the viewpoint of equipment cost.

[0028]

[Embodiments] In the following, embodiments of the present invention in which the continuous casting system having a configuration shown in Fig. 1 is used are explained.

[0029] With a continuous casting system whose sectional dimension of a slab is 220 mm in thickness and 1200 mm in width, ultra low carbon Al-killed steel having a carbon concentration of 0.005% by weight is cast under a slab extruding speed of 2.5 m/min. The submerged nozzle used here has a discharge opening diameter of 85 mm, a discharge opening angle of 25 degree declivity and a submersion depth of the submerged nozzle (a distance from the meniscus to an upper end of the discharge opening) is 230 mm. Furthermore, the meniscus is positioned at 120 mm from a top end of the mold and a length of the mold is 950 mm.

[0030] The upper magnetic pole has a length of 240 mm in a casting direction, a length of 1950 mm in a mold width direction, and the meniscus is disposed so that it may be located at 100 mm from a top end of the upper magnetic pole in a casting direction. Furthermore, the lower magnetic pole has a length of 240 mm in a casting direction and a length of 1950 mm in a mold width direction, and a center position in the casting direction is disposed at 250 mm from a bottom end of the discharge opening. This is positioned upward in the casting direction than a point where the discharge flow collides the solidified shell on the short sidewall side. For both of the

upper magnetic poles and the lower magnetic poles, a width of the convexity around which the coil for use in both the direct current and the alternating current is wound is 225 mm and six convexities are provided to each of the magnetic poles.

[0031] For the alternating current, a three-phase alternating current source having a frequency of 60 Hz is used. In the present embodiment, as a method for generating a magnetic field in which the static magnetic field and the alternating shifting magnetic field are superposed, a method in which the direct current and the alternating current are applied superposed to the coil for use in both the direct current and the alternating current is used.

[0032] Although a target magnetic flux density of the static magnetic field at the center of the thickness of the mold is set at 0.25 T, when the direct current and the alternating current are applied superposed, there are cases where the static magnetic field decreases to substantially 0.2 T under an influence of the alternating shifting magnetic field. Furthermore, the magnetic flux density of the alternating shifting magnetic field at the inner wall of the mold is varied in the range of 0.12 T to 0.45 T, and adjusted, under the conditions where matching with the static magnetic field can be established, to the maximum value in the range where the flow of the molten steel at the meniscus is not disturbed. The magnetic fields of the upper magnetic poles and the lower

magnetic poles are applied in combinations shown in Table 1.

[0033]

[Table 1]

Magnetic field apply conditions and cleanliness of slabs (applied superposed to the same coil)

| | Magnetic field apply condition | | Evaluation of cleanliness of slab |
|---|---|---|---|
| | Upper magnetic pole | Lower magnetic pole | |
| Embodiments of the present invention | Direct current | Direct current + alternating current | ++ |
| | Alternating current | Direct current + alternating current | ++ |
| | Direct current + alternating current | Direct current + alternating current | +++ |
| | Direct current + alternating current | Direct current | ++ |
| Comparative embodiments | Direct current | Direct current | + |
| | Alternating current | Direct current | + |
| | Direct current | Alternating current | + |
| | Alternating current | Alternating current | + |
| | Direct current + Alternating current | Alternating current | + |

+++; Effective
++; Relatively effective
+; Not effective

[0034] Furthermore, for comparison purpose, there are included cases where only the direct current or the alternating current is applied to the upper magnetic poles and the lower magnetic poles, and where the direct current and the alternating current are applied superposed to the upper magnetic poles and only the alternating current is applied to the lower magnetic poles. The magnetic field apply conditions of the comparative embodiments are also shown in Table 1.

[0035] The obtained slab is rolled to a steel sheet, and the steel sheet is exposed to an ultrasonic inspection to

investigate defect occurrence due to the nonmetallic inclusions. Ones low in the defect occurrence are evaluated high in the cleanliness. Results are shown in Table 1. As shown in Table 1, in the embodiments of the present invention, the cleanliness of the slab is improved.

[0036] [Embodiment 2] In the present embodiment, as a method for forming a magnetic field in which the static magnetic field and the alternating shifting magnetic field are superposed, the alternating current is applied to the coil for use in both the direct current and the alternating current and the direct current is applied to the direct current coil. Other conditions than the above are completely the same as those of the embodiment 1.

[0037] Even when the magnetic field in which the static magnetic field and the alternating shifting magnetic field are superposed is generated, in the present embodiment where the alternating current and the direct current are independently applied, the conditions for matching the static magnetic field and the alternating shifting magnetic field can be alleviated, the magnetic flux density can be relatively freely decided, that is, the magnetic flux density of the static magnetic field at the center of the thickness of the mold can be always maintained at 0.25 T or more. The magnetic fields of the upper magnetic poles and the lower magnetic poles are applied in combinations shown in Table 2.

[0038]

[Table 2]

Magnetic field apply conditions and cleanliness of slabs (applied to separate coils)

| | Magnetic field apply condition | | Evaluation of cleanliness of slab |
|---|---|---|---|
| | Upper magnetic pole | Lower magnetic pole | |
| Embodiments of the present invention | Direct current | Direct current + alternating current | +++ |
| | Alternating current | Direct current + alternating current | +++ |
| | Direct current + alternating current | Direct current + alternating current | ++++ |
| | Direct current + alternating current | Direct current | +++ |
| Comparative embodiments | Direct current + Alternating current | Alternating current | + |

++++; Very effective
+++; Effective
++; Relatively effective
+; Not effective

[0039] Furthermore, as a comparative embodiment, a case where the direct current and alternating current are applied superposed to the upper magnetic poles and only the alternating current is applied to the lower magnetic poles is carried out.

[0040] The obtained slab is rolled to a steel sheet, and the steel sheet is exposed to an ultrasonic inspection to investigate defect occurrence due to the nonmetallic inclusions. Ones low in the defect occurrence are evaluated high in the cleanliness. Results are shown in Table 2. As shown in Table 2, in the embodiments of the present invention where the direct current and the alternating current are independently applied, the cleanliness of the slabs is

furthermore improved. In particular, under the conditions of the direct current and the alternating current being applied to both the upper magnetic poles and the lower magnetic poles, the maximum cleanliness can be secured.

[0041]

[Effects of the Invention] In the present invention, by use of a static magnetic field disposed below the discharge opening, the descending flow is inhibited from intruding into the un-solidified layer of the slab, resulting in an improvement in the cleanliness of the inner layer of the slab, and since the flow due to the ascending flow in the neighborhood of the meniscus is suppressed, the inclusion of the mold powder is largely reduced, and furthermore, since the molten steel is rotated and agitated in a horizontal direction by the alternating shifting magnetic field, the effect of cleaning the nonmetallic inclusions in the solidified shell interface can be secured, resulting in an improvement in the cleanliness at the slab surface portion. As a result, the slab clean in both the internal layer and surface layer can be stably produced.

[Brief Description of the Drawings]

Fig. 1 is a schematic sectional front view of a mold of a continuous casting system to which the present invention is applied and in which a slab section is rectangular.

Fig. 2 is a schematic sectional side view of a mold of

a continuous casting system to which the present invention is applied and in which a slab section is rectangular.

Fig. 3 is a schematic diagram along an X-X section of Fig. 2.

Fig. 4 is a schematic diagram showing a sectional side view of a continuous casting system according to another embodiment of the present invention.

[Description of the Reference Numerals and Signs]

1 --- mold

2 --- long sidewall of mold

3 --- short sidewall of mold

4 --- molten steel

5 --- submerged nozzle

6 --- discharge opening

7 --- upper magnetic pole

8 --- lower magnetic pole

9 --- coil for use in both direct current and alternating current

10 --- direct current coil

11 --- return yoke

12 --- discharge flow

13 --- solidified shell

14 --- meniscus

15 --- mold powder